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AFFERENT IMPULSES OF THE TRIGEMINAL NERVE

THE INTRAMEDULLARY COURSE OF THE PAINFUL, THERMAL AND TACTILE IMPULSES

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AFFERENT IMPULSES OF THE TRIGEMINAL NERVE

THE INTRAMEDULLARY COURSE OF THE PAINFUL, THERMAL AND TACTILE IMPULSES

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
OF NORTHWESTERN UNIVERSITY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

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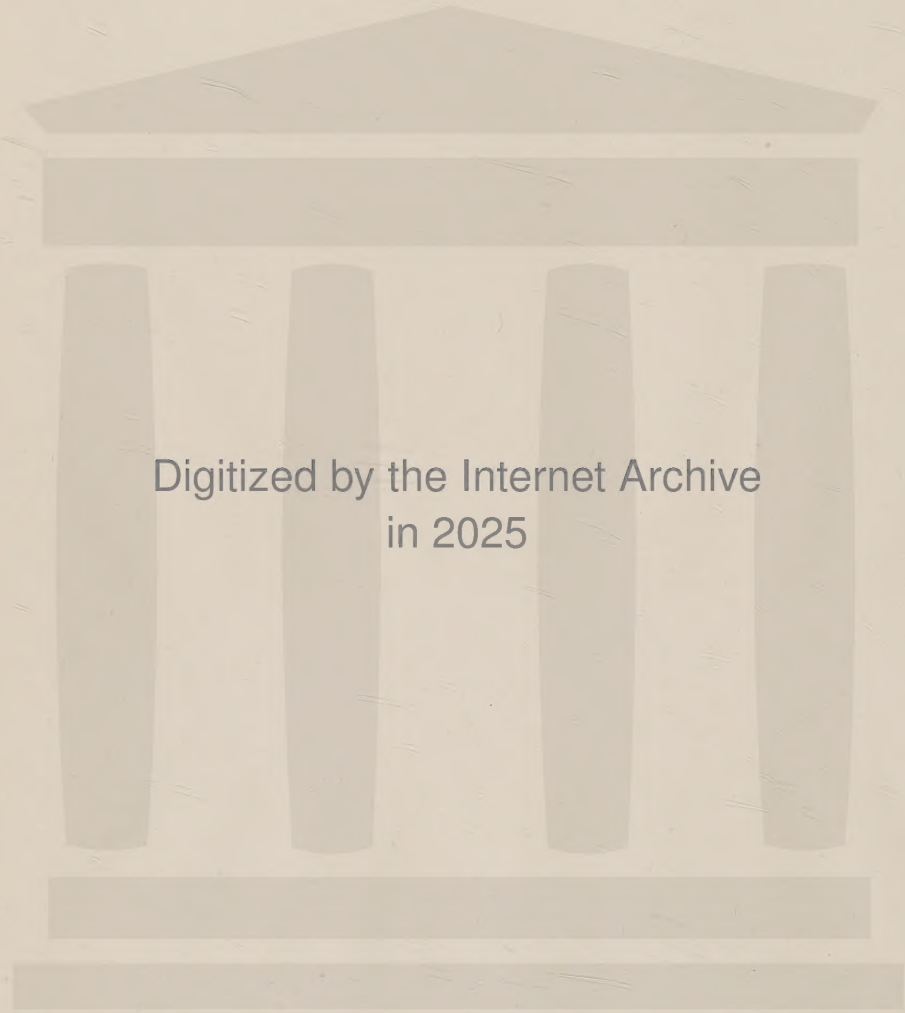

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AFFERENT IMPULSES OF THE TRIGEMINAL NERVE

THE INTRAMEDULLARY COURSE OF THE PAINFUL, THERMAL AND TACTILE IMPULSES *

MARGARET WILSON GERARD

CHICAGO

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I. INTRODUCTION

ANATOMY OF THE TRIGEMINAL NERVE

The trigeminal nerve is composed of a large sensory division whose unipolar cells are in the Gasserian ganglion, and a small motor division distributed entirely through the mandibular branch of the nerve. The skin of the face and the mucous membrane of the mouth, tongue, and nose are supplied by pain, tactile, and thermal fibers which pass into all three branches of the trigeminal nerve; these are the ophthalmic, maxillary and mandibular nerves. The cornea differs from other parts of the face, in that only painful sensations may be elicited by stimulation of this region (Schäfer,[1] 1900). Sensory fibers also accompany the motor root into the brain stem, their unipolar cells of origin forming the mesencephalic nucleus, which is an unusual location for sensory cells. These fibers are believed to be proprioceptive and to supply

* Contribution No. 98 from the anatomic and physiologic laboratories, Northwestern University Medical School.

1. Schäfer, E. A.: Text-Book of Physiology, London, Longmans, Green & Co. **2**:987, 1900.

the muscles innervated by the motor division of the trigeminal nerve (Willems,[2] 1911, Allen,[3] 1919). The main sensory root carries the usual cutaneous sensations.

In cross section, the trigeminal nerve in the cat was seen to consist of fibers varying from unmyelinated fibers of 1.5 microns to the largest myelinated fibers of 16 microns. These latter belonged to the motor root and were always found on the dorsal surface of the nerve. There were very few of them, only 46 and 42 in two nerves counted,[4] the majority of the motor fibers being between 10.8 and 11.7 microns in diameter. In two nerves 370 and 390 fibers of this size were found. Many of these, however, must be considered as sensory rather than motor since they occupied a more ventral position than any of the motor fibers.

The majority of the sensory fibers ranged from 5.3 to 8 microns in diameter and were scattered evenly throughout the sensory part of the nerve. In different specimens 2480 and 2459 of these fibers were counted. Intermediate fibers of 3.7 to 4 microns numbered 274 and 204 in the two different nerves, and fibers smaller than 3 microns appeared in equal numbers. In the pyridin silver preparations several bundles of unmyelinated fibers (392 and 400 in two different nerves) were seen scattered between the larger fibers. The small number of unmyelinated fibers in the trigeminal nerve is in marked contrast to the conditions in most other nerves, which contain numerous unmyelinated fibers (Kock,[5] 1916).

In the cat the nerve is directed caudad and pierces the pons in the rostral ventrolateral region, and makes a slight curve dorsad (Fig. 1). The motor fibers separate almost immediately from the others and divide into several small bundles which pierce the pontine fibers and pass dorsad to the motor nucleus. The sensory division continues 0.5 to 1 millimeter caudad, and then breaks into a main sensory portion which passes dorsad to the main sensory nucleus, and a spinal tract which extends caudad into the medulla. Cajal,[6] 1896, in a very com-

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2. Willems, E.: Les noyaux masticateurs et mésencéphaliques du trijumeau, Le Névraxe **12**:7, 1911.

3. Allen, W. F.: Application of the Marchi Method to the Study of the Radix Mesencephalica Trigemini in the Guinea-Pig, J. Comp. Neurol. **30**: 169, 1919.

4. The fiber counts of two or three different nerves are presented always in the same sequence—those from nerve A being given first, etc. The counts were made by enumerating the fibers in successive fields under the microscope, the stage being arranged to move in such manner that the lines of all series were parallel.

5. Kock, S. L.: The Structure of the Third, Fourth, Fifth, Sixth, Ninth, Eleventh and Twelfth Cranial Nerves, J. Comp. Neurol. **26**:541, 1916.

6. Cajal, S. R. y: Beitrag zum Studien der Medulla Oblongata, 1896.

prehensive description of the trigeminal nerve, claimed that the two sensory parts are formed from the sensory division by the splitting of each individual fiber in it, into a small branch passing to the main sensory nucleus and a larger branch passing to the spinal nucleus. In sections of brains of new-born rats and rabbits, prepared by the Golgi silver impregnation method, he was able to see this bifurcation. Since, with this method, all the fibers are never impregnated, it would be

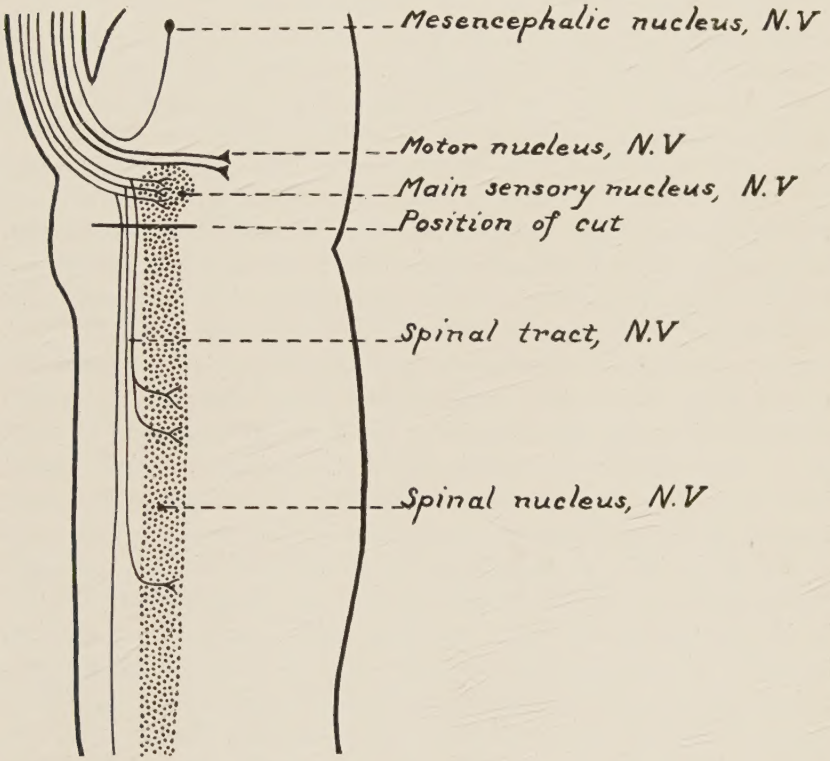

Fig. 1.—Diagram of a longitudinal section of the medulla, showing the central connections of the fifth nerve and the position of the experimental lesion.

impossible to determine whether or not every fiber bifurcates. Indeed, Kölliker,[7] asserted that all the fibers do not do so, while Held,[8] confirmed Cajal's description. That many of the fibers do bifurcate is evident in the pyridin silver preparations which we have examined, though it is not certain that all do. Actual bifurcations may be seen in

7. Kölliker, A.: Der feinere Bau des verlangerten Markes, Anat. Anz. **6**: 427, 1891.

8. Held, H.: Die Endungsweise der sensiblen Nerven im Gehirn, Arch. f. Anat. u. Phys., 1892, p. 33.

many cases, and there is a noticeable increase in the total number of fibers as the nerve approaches the point of separation of the two divisions. This increase is mainly in the smaller fibers which are seen to pass to the main sensory nucleus. It may be noted that in no case are any of the unmyelinated, or the small myelinated, fibers seen to branch, indicating that these may, perhaps, pass entire into the spinal tract.

The descending or spinal tract forms, in the brain stem, a half-moon shaped bundle which caps the peripheral edge of the spinal trigeminal nucleus. In this bundle one can distinguish a superficial layer composed of vertical fibers only, and a deeper layer of vertical interlaced with horizontal fibers. The latter fibers are terminations and collaterals on their way to the spinal nucleus. Within the nucleus the fibers form a diffuse network between the individual cells. Kölliker.[7] believed that, besides the endings in the substantia gelatinosa, there were collaterals which passed to the motor nuclei of the trigeminal, facial and hypoglossal nerves. Obersteiner,[9] 1912, confirmed this observation, though Cajal[6] 1896, had strongly denied it. In 1902, Breuer and Marburg[10] described a bundle of fibers in the medial part of the tract, which they named "fibrae concomitantes", and which passed, in their opinion, through the spinal trigeminal nucleus to reach the nucleus solitarius, in which the tract terminated. Wallenberg,[11] 1904, again mentioned this bundle and suggested that it carried taste fibers from the mucous membrane of the mouth.

Cajal,[6] in 1896, claimed to have traced the spinal fifth tract to a region just below the bifurcation of the pyramids. Wallenberg,[12] found in Marchi preparations from cats and rabbits whose fifth nerve had been cut, evidence of degeneration as low as the first cervical segment. Kljatschin,[13] 1897, with a similar technic, followed the degeneration to the second cervical segment. Other investigators, Pomatowsky,[14] in 1892, and Obersteiner[9] in 1912, asserted that the tract extended to

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9. Obersteiner, H.: Anleitung beim Studien des Baues der nervösen Centralorgane in gesunden und kranken Zustände, Leipzig, 1912, p. 533.

10. Breuer, R., and Marburg, O.: Zur Klinik und Pathologie der apoplectiformen Bulbarparalyse, Arb. a. d. Neurol. Inst. a. d. Univ. Wien **9**:181, 1902.

11. Wallenberg, A.: Anatomischer Befund in einen als "Blutung in die rechte Brückenhalfte usw. aus dem Ram. Central. Arter. radicular N. facialis dextri" geschilderten Fälle, Deutsch. Ztschr. f. Nervenheilk. **27**:436, 1904.

12. Wallenberg, A.: Die secondäre Bahn des sensiblen Trigeminus, Anat. Anz. **12**:95, 1896.

13. Kljatschin, G.: Experimentelle Untersuchungen über den Ursprung des N. Trigeminus, Neurol. Centralbl. **16**:204, 1897.

14. Pomatowsky, A.: Ueber die Trigeminus-Wurtzel im Gehirne des Menschen, Arb. a. d. Inst. f. Anat. u. Phys. d. centr. Nervensyst., Wien **1**:98.

the second or third cervical segments. Gudden [15] in 1892, after examining a calf with unilateral trigeminal aplasia, concluded that the spinal tract extended to the fifth cervical segment. Dejerine [16] in 1914, considered the fourth cervical segment as the termination of the tract. In our preparations by the Pal-Weigert and pyridin silver methods, from cats in which one fifth nerve had been cut and allowed to degenerate, we found no evidence of degeneration below the upper level of the second cervical segment. This is in agreement with the evidence of Kljatschin, who based his conclusions upon Marchi preparations.

In examining the cross sections at various levels of the brain stem of the cat and of man, we found that in the lower levels of the tract there was a greater proportion of small myelinated fibers than in the upper levels, and at the lowest limits there was an actual increase in the number of unmyelinated fibers. As seen in cross section, the fibers of different sizes were evenly distributed, but were united into bundles of various sizes by the horizontal fibers, which had changed their direction to end in relation with the cells of the spinal fifth nucleus.

The largest fibers in the spinal fifth tract of the cat measured 9.9 to 10.1 microns in diameter. These were not very numerous at any point and gradually decreased in number as the tract descended. In two different brain-stems stained with the Pal-Weigert and pyridin silver methods, 149 and 157 fibers respectively were counted in the region of the superior olive. At the upper level of the inferior olive these fibers had decreased in number to 99 and 117, and a third preparation contained 129 in this region. At the lower level of the inferior olive 34, 15, and 27 were found, while at the decussation of the pyramids, there were 17, 8, and 14. In lower sections no fibers of this size were found.

Fibers of 5.3 and 8 microns in diameter were more numerous than the larger fibers and numbered 893 and 921 at the superior olive; 713, 718, and 697 at the upper level of the inferior olive; 612, 679, and 631 at the lower level of the inferior olive; and 312, 298, and 287 in the region of the decussation of the pyramids. All of these disappear above the upper level of the first cervical segment.

Fibers of 3.7 to 4.8 microns were found to be very numerous; 1102, and 1080 in the superior olivary region; 853, 839, and 872 at the upper level of the inferior olive; 704, 622, and 661 at the lower level of the olive; 417, 423, and 432 at the decussation of the pyramids; and 210, 197, and 184 in the upper region of the first cervical segment.

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15. Gudden, H.: Beitrag zur Kenntniss der Wurtzeln des Trigeminus Nerven, Allg. Ztschr. f. Psych. **48**:16, 1892.

16. Dejerine, J.: Sémiologie des affections du système nerveux **2**:800, 1914.

Myelinated fibers smaller than the last were equally numerous; 1161 and 1143 at the superior olive; 1109, 1134, and 1124 at the upper level of the inferior olive; 495, 472 and 392 at the decussation of the pyramids; and 149, 139 and 153 at the upper level of the first cervical segment.

The unmyelinated fibers in the pyridin silver preparations numbered 506 at the superior olive, 443 at the upper level of the inferior olive, 408 at its lower level, 392 at the decussation of the pyramids, and 502 at the upper level of the first cervical segment.

In the human brain-stem, the same relative proportion of the various sizes of fibers was found, although the fibers in each group averaged slightly larger than those of the cat; the largest being 11.3 microns instead of 10.1 microns.

To sum up this description, there is a decrease in the size and number of the fibers in the path as it descends; the larger fibers drop out entirely, as do some of the smaller ones, but many of the myelinated and unmyelinated fibers descend to the end of the tract. This indicates either that the larger fibers terminate in the upper levels of the tract or that, as a result of giving off collaterals on the way, they continue to the lower levels as smaller fibers. The actual increase in the number of unmyelinated fibers may be due to the loss of the myelin sheaths of the smaller fibers as they reach the lower levels, or, possibly, to the upward continuation into the spinal fifth tract of fibers from the tract of Lissauer, which is largely composed of unmyelinated fibers (Ranson,[17] 1913). Since there is no line of demarcation between the tract of Lissauer in the upper cervical segment of the cord and the lower level of the spinal fifth tract, it is possible that those earlier observers who did not use Marchi technic confused these two fiber bundles, with a consequent disagreement on the actual boundary.

FUNCTIONAL DIVISIONS OF THE SPINAL TRIGEMINAL TRACT

The different branches of the fifth nerve seem to retain their identity within the spinal tract. Bregmann,[18] 1892, after partially cutting the sensory root, observed a disturbance of painful sensibility in the ophthalmic division of the nerve and a degeneration in the ventral part of the tract. When the degeneration was in the dorsal part of the tract, sensibility in the maxillary and mandibular regions was involved. Obersteiner[9] in 1912, described a similar distribution and further localized the fibers of the maxillary division in the medial part of the tract.

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17. Ranson, S. W.: The Course within the Spinal Cord of the Nonmedullated Fibers of the Dorsal Roots: A Study of Lissauer's Tract in the Cat, J. Comp. Neurol. **23**:259, 1913.

18. Bregmann, E.: Ueber experimentelle aufsteigende Degeneration motorischen und sensiblen Hirnnerven, Arb. a. d. Inst. f. Anat. u. Phys. d. centr. Nervensyst., Wien **1**:73.

Other investigators have suggested that the different branches of the nerve also terminated at different levels of the tract. Solder [19] in 1899, and Schlesinger [20] in 1902, believed that the frontal branch of the ophthalmic nerve extended the whole length of the spinal tract, the mandibular ended just above, the maxillary still higher, and the nasociliary branch of the ophthalmic extended only into the highest part of the tract. This arrangement was indicated in cases of syringomyelia, with a lesion proceeding rostrad through the medulla, in which the analgesia which resulted from the disease progressed in the form of narrowing circles from the periphery of the face, until only the nose and the medial side of the eye were left intact in the last stages of the disease. A case described by Woods [21] in 1913, showed a similar area of analgesia surrounding the nose and eye.

Kutner and Kramer,[22] 1907, and Wallenberg,[11] 1904, suggested a slightly different arrangement. According to them, the whole ophthalmic division extended to the lowest level of the tract, the maxillary not so far, and the mandibular division ended near the top. They also stated that the fibers from the lingual and buccal mucous membranes occupied the dorsal part of the spinal tract, while the fibers from the conjunctiva and the nasal mucosa were situated in the ventral part of the tract. In 1914, Dejerine,[16] claimed that the area of analgesia centered around the nose and mouth.

In general, then, it may be said that the fibers supplying the most peripheral part of the face extend further down the spinal tract, while those supplying the central area terminate nearer to the beginning. It may also be said that those which extend further down the tract probably run ventrad to those which terminate at a higher level.

BLOOD SUPPLY FOR THE SPINAL FIFTH TRACT AND NUCLEUS

For the purpose of this investigation a consideration of the blood supply of the lateral area of the medulla, through which the spinal tract of the fifth nerve passes, is of prime importance. This area is supplied principally by the posterior inferior cerebellar artery. According to Stopford,[23] 1916, this is the largest branch of the vertebral

19. Von Solder, F.: Der segmentale Begrenzungstypus bei Hautanaesthesien am Kopfe, inbesondere in Fälle von Syringomyelie, Jahrb. f. Psychiat. **18**: 458, 1899.

20. Schlesinger, H.: Die Syringomyelie, 1902, p. 162.

21. Woods, A. H.: Segmental Distribution of the Spinal Root and Nucleus of the Trigeminal Nerve, J. Nerv. & Ment. Dis. **40**:91, 1913.

22. Kutner, R., and Kramer, F.: Sensibilitätstörungen bei akuten und chronischen Bulbärerkrankungen, Arch. f. Psychiat. **42**:1002, 1907.

23. Stopford, J. S.: The Arteries of the Pons and Medulla Oblongata, J. Anat. & Physiol. **50**:131 and 254, 1916.

artery, and arises from its side at the lower end of the olive. "After curving round the lower border of the olive, it ascends in the neighborhood of the posterior lateral sulcus, usually posterior to the fila of the vagus and glossopharyngeal nerves, almost to the lower border of the pons, where it changes its direction and forms a loop with its convexity toward the pons. It now proceeds downwards, with a slight inclination toward the midline, on the restiform body and the other inferolateral boundaries of the fourth ventricle, to just below the calamus scriptorius, where it turns outward on to the vallecula to divide into its fully described lateral and medial branches, for the supply of the inferior surface of the cerebellum."

In the brain stem, Stopford found that the injected area was limited ventrally by the inferior olive, laterally by the tegmento-olivary tract, and medially by the fibers of the hypoglossal nerve. This area would therefore include the following structures:

1. Spino-thalamic tract.
2. Rubro-spinal tract.
3. Olivo-cerebellar fibers as they pass to the inferior cerebellar peduncle.
4. Dorsal vago-glossopharyngeal nucleus of the emerging fibers of the vagus and glossopharyngeal nerves.
5. Nucleus ambiguus.
6. Nucleus and tractus spinalis of the trigeminal nerve.
7. Ventral part of the inferior cerebellar peduncle.

We have found no record of experimental evidence which indicates a differentiation in the functions of the main sensory nucleus and the spinal nucleus. On the other hand, there have been many clinical cases recorded in the literature which suggest this possibility. Cases of occlusion of the posterior inferior cerebellar artery, strongly suggest that the pain and temperature fibers of the fifth cranial nerve terminate within the spinal nucleus of that nerve, while the fibers carrying tactile sensations terminate more rostrad in the main sensory nucleus. Cases of syringomyelia or of hemorrhage into the medulla which caused destruction of one or the other nucleus gave similar results. These cases have not as yet been collected, and the evidence which they offer has not been focused on the problem of sensory conduction in the trigeminal nerve. The investigation which I am here reporting represents an endeavor to assemble the clinical data and to secure experimental evidence on the question of such a differentiation.

II. CLINICAL DATA

SYMPTOM-COMPLEX OF OCCLUSION OF THE POSTERIOR INFERIOR CEREBELLAR ARTERY

The symptoms which occur after occlusion of the posterior inferior cerebellar artery are remarkably constant and, in order to simplify the

presentation of the clinical evidence, they may be summarized in accordance with Gordinier,[24] 1911:

1. Sudden onset, usually without loss of, or disturbance in consciousness.

2. Diminution or loss of sensibility to pain and temperature in the area of distribution of the fifth nerve on the side of the lesion.

3. Diminution or loss of sensibility to pain and temperature in the limbs of the side opposite to the lesion, very rarely also, in the side of the face opposite the lesion. (This indicates an involvement of the secondary trigeminal path).

4. No paralysis or paresis of the muscles innervated by the trigeminal nerve.

5. Spontaneous pain or some form of paresthesia in the area of disturbed objective sensibility.

6. Tactile sensibility intact in all parts.

7. Sensibility of position usually intact.

8. Rarely a zone of intact sensibility in the region of the neck, between the area of disturbed sensibility in the face on the one side and that of the limbs on the other.

9. Tendency to fall or sway toward the side of the lesion, and for the head to drop forward toward the same side.

10. Bilateral nystagmus, more intense when the eyes are directed toward the side of the lesion.

11. Menière's syndrome of vertigo, revolving vertigo, auditory hallucinations, vomiting, and deafness on the side of the lesion.

12. Paralysis of the muscles of deglutition on the side of the lesion, with impaired sensibility of the pharynx.

13. Paralysis of the soft palate and larynx on the side of the lesion; vocal cords immobile in a cadaveric position; the voice hoarse and the speech merely a whisper.

14. The tongue, rarely, is a little weak on the side of the lesion, but the weakness usually soon passes away.

15. Taste may occasionally be lost on the anterior two-thirds of the tongue.

16. The facial and abducens nerves are not involved in the lesion.

17. Small pupil, ptosis, narrow palpebral fissure, and retraction of the eyeball on the side of the lesion.

18. Loss of sweating of the face on the side of, or on the side opposite to the lesion.

19. Persistent hiccough.

20. The pulse may be rapid (from paralysis of the vagus) or slow (from irritation of the vagus).

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24. Gordinier, H. C.: Occlusion of the Posterior Inferior Cerebellar Artery, a Definite Symptom Complex, Albany M. Ann. **32**:585, 1911.

These symptoms are so typically constant, that they may be considered as a syndrome. For this reason, it will not be necessary to discuss the symptoms of the following cases at length, and those symptoms alone will be detailed which bear directly on the sensory defects in the trigeminal area.

Unfortunately, a clinical examination is not always as complete nor as carefully executed as one might desire, so that a number of the cases here reported lack adequate detail, and are of value only to confirm those which are more complete. For example, the clinician reports a "disturbance" in temperature or pain sensibility but does not state the manner of variation from normal. In some of the cases there was no mention of the integrity of certain sensibilities, and we must conclude that such sensibilities were not examined. In some cases diagnosed as "probable occlusion of the posterior inferior cerebellar artery," the sensory disturbances of the face and of the body were on the same side; this indicates involvement of the secondary paths of the fifth nerve rather than of the primary path. These cases, therefore, were either incorrectly diagnosed, or were so atypical that no conclusions on the distribution of the fibers of the fifth nerve may be drawn; they have consequently been omitted.

CLINICAL CASES OF OCCLUSION OF THE POSTERIOR INFERIOR CEREBELLAR ARTERY

Case 1.—The first case on record is that of Senator,[25] 1881. He tested for painful sensibility with a pin or needle prick, and with cotton wool for tactile sensibility. Tests for temperature were not recorded. Examination disclosed an area of total analgesia which included the left side of the forehead, nose, cheek, lips and chin, just to the midline; the sensibility to pain on the whole right side of the face remained intact. The tactile sensibility of the left side, on the contrary, was, when compared with the right side, little, if at all, impaired.

The necropsy disclosed a thrombus in the left vertebral artery, which extended into the posterior inferior cerebellar branch, and into the anterior spinal artery, and occluded them both. The resultant necrosis in the medulla was spindle shaped in cross-section and stretched from the middle of the olive to the lowest of the hypoglossal rootlets. It included among other structures (the restiform body, the border of the cuneate fasciculus, the motor nucleus of the vagus, part of the vagus fibers, part of the inferior olive, the accessory olivary nuclei, and the roots of the hypoglossal nerve), the spinal root of the trigeminal nerve, which was therefore destroyed, while the main sensory and motor nuclei of the trigeminal nerve, which were above the lesion, had remained intact.

Case 2.—Another case was reported in 1881 by Remak.[26] The symptoms were typically those of occlusion of the posterior inferior cerebellar artery,

25. Senator, H.: Apoplektische Bulbärparalyse mit wechselständiger Empfindungslähmung, Arch. f. Psychiat. **11**:713, 1881.

26. Remak, R.: Krankenvorstellung eines Falles vom Hemianaesthesia alterans, Berl. klin. Wchnschr. **18**:300, 1881.

although there was no necropsy, and included, an analgesia on the right side of the face, which was particularly marked on the forehead and eyeball, and was accompanied by persistent spontaneous pain in the same regions. The activity of the motor fibers of the trigeminal nerve was entirely normal.

Case 3.—In 1883, Senator[27] reported a case with necropsy. He tested for painful sensibility with a needle prick, but failed to mention his method of tactile examination. Temperature sensibility was not mentioned. The sensation of touch was normal on both sides of the face while needle prick on the left cheek, nose and inside of the nostril produced only tactile sensations.

At the necropsy a thrombus was found in the left vertebral artery. It occluded the lumen for a considerable distance, and also the opening of the posterior inferior cerebellar artery. The resulting lesion in the medulla spared the main sensory and motor nuclei of the trigeminal nerve, but included the descending or spinal root of this nerve, together with the vagal roots and nucleus, the restiform body, the fasciculus solitarius, the nucleus and roots of the hypoglossal nerve, and the cochlear nuclei and part of the olive.

Case 4.—Wallenburg[28] announced the next case in 1895, though the necropsy report did not appear until 1901.[29] He did not detail his methods of testing the various sensibilities, but reported anesthesia to cold, painful and electrical cutaneous stimuli, on the whole of the left side of the face.

The necropsy in this case revealed an obturating thrombus in the left posterior inferior cerebellar artery. There was also a parietal thrombus in the right posterior inferior cerebellar artery, which only slightly narrowed the lumen. Microscopic examination of the medulla disclosed an anemic necrosis which included the ventral two-thirds of the spinal root and nucleus of the trigeminal nerve.

Case 5.—Mann,[30] 1892, reported a case which he termed encephalomalacia medullae oblongatae. There was no necropsy to determine the etiology, but the symptoms were similar to those which follow occlusion of the posterior inferior cerebellar artery. An area of the right side of the face which extended from the vertex capitis to the chin and from the anterior edge of the ear to the midline, showed a marked reduction in pain, temperature and electrocutaneous sensibility and also a subjective burning pain. The mucous membrane of the right cheek also showed a reduction in painful sensibility. Tactile sensibility on the right side of the face, on the other hand, was entirely normal, as was all sensibility on the left side of the face.

Case 6.—In 1897, Hun[31] published an excellent, detailed discussion of a case which had come under his observation. He tested for painful sensibility with a pin prick, and for thermal sensibility with test tubes filled with hot or cold water. Examination of the patient revealed that the left side of the

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27. Senator, H.: Zur Diagnostik der Herderkrankungen in der Brücke und dem verlängerten Mark, Arch. f. Psychiat. **14**:643, 1883.

28. Wallenberg, A.: Acute Bulbäraffection (Embolie der Art. Cerebellaris Post. Inf. Sinistra?), Arch. f. Psychiat. **27**:504, 1895.

29. Wallenberg, A.: Anatomischer Befund in einem als "akute Bulbäraffektion (Embolie der Art. Cerebellaris Post. Inf. Sinistra?)" beschreibenen Falle, Arch. f. Psychiat. **34**:923, 1901.

30. Mann, L.: Casuistischer Beitrag zur Lehre von central entstehenden Schmerz, Berl. klin. Wchnschr. **29**:244, 1892.

31. Hun, H.: Analgesia, Thermic Anaesthesia and Ataxia, New York M. J. **65**:613, 1897.

face and tongue, the inside of the left nostril, the right arm, right leg and right side of the body were entirely normal in tactile sensibility but were absolutely insensitive to pain and to differences in temperature. There were: decreased sweating on the left side of the face, a slight ptosis of the left eyelid, and, when the disease progressed, an appearance and gradual spread of left facial paralysis. All the muscles of mastication on both sides were spared which proved that the motor nucleus of the trigeminal was intact. Later, a partial sensitivity to painful stimuli returned in the body regions, but not on the face.

The examination of the brain at the necropsy was performed by Van Gieson, who reported that areas of softening existed on the left side, in the medulla, lower pons, and cerebellum, and that no lesions were found elsewhere. Histologic examination showed that the destruction involved the spinal tract and nucleus of the fifth nerve (as well as: the dorsal spinocerebellar tract; the column of Gowers; the fibers which pass between the cerebellum and inferior olive; part of the gray reticular formation; the motor nuclei of the glossopharyngeal and vagus nerves; and a very small part of the inferior olive), but did not include its main sensory and motor nuclei. The degeneration of the spinal fifth tract was complete, and extended to the upper part of the first cervical segment which Van Gieson claimed to be the lowest level of the tract.

Case 7.—Wallenberg,[32] 1901, reported a case which bore the earmarks of occlusion of the posterior inferior cerebellar artery, though the case did not come to necropsy (the patient was still living when the report was made). He found the usual hypalgesia and hypothermesthesia in the region supplied by all three branches of the right trigeminal nerve, which included the mucous membrane of the mouth and tongue. The areas of greatest disturbance were: the right temple, the right eye, the bridge of the nose, the slightest area about the angle of the jaw, and the ears and chin. Wallenberg mentioned a disturbance in tactile sensibility on the left side of the body, but made no reference to touch in relation to the face. It seems legitimate to conclude that, had there been any disturbance in tactile sensibility of the face, he would have mentioned it also.

Cases 8 and 9.—In 1902, Breuer and Marburg[10] reported two cases with necropsies. In the first one, the clinical examination revealed no disturbance on the right side of the face nor of the motor functions or tactile sensibility on the left. The region of the left side of the face supplied by the third branch of the fifth nerve, however, was insensitive to painful stimuli and was also the seat of a subjective pain.

At necropsy, a thrombus, which entirely occluded the opening of the posterior inferior cerebellar artery, was found in the left vertebral artery. Marchi preparations of the medulla showed areas of degeneration which included: the left spinal fifth tract below the level of the upper border of the decussation of the lemnisci; a bundle lateral to the posterior longitudinal bundle (the central fifth tract of Wallinger); and a bundle dorsal to the medial lemiscus (the ventral Haubenfeld of Spitzen, which is also a central fifth path).

The report of the second case was rather incomplete. There was no disturbance in motor activity of any part of the body, the sensibility to painful

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32. Wallenberg, A.: Klinische Beiträge zur Diagnostik akuter Herderkrankungen des verlängerten Markes und der Brücke, Deutsch. Ztschr. f. Nervenheilk. **19**:225, 1901.

and tactile stimuli was intact on both sides of the face and the right side of the face was also sensitive to thermal stimuli. But the left side of the face did not respond to cold.

The necropsy disclosed a thrombus in the left vertebral artery. The resultant lesion in the medulla involved a small part of the left trigeminal tract in its whole length; which particular part, was not specified.

Case 10.—Rossolimo,[33] in 1903, described a patient (Case 5 of his report) whose symptoms were typically those of occlusion of the posterior inferior cerebellar artery, and though unconfirmed by necropsy, the case may be regarded as such. The patient showed marked disturbances of pain and temperature sensation in all areas innervated by branches of the left trigeminal nerve. In that portion of this area supplied by the maxillary division, there was also a subjective neuralgia. The right half of the body showed no disturbance in pain and temperature.

Case 11.—In 1903, Mai[34] also reported a case of this type. An area of the right side of the face, reaching from the midline to a curve connecting the outer corner of the eye, the anterior part of the ear, and the corner of the mouth, and from the upper lip to the vertex capitis, was insensitive to pain and thermal stimuli. Tactile sensibility was absolutely normal over the whole body.

The necropsy disclosed a thrombus in the right vertebral artery, which partially occluded it and completely occluded the posterior inferior cerebellar artery. The resulting anemic necrosis in the right medulla included (besides a small part of the olive, the lateral nucleus, the nucleus ambiguus and the internal and external arcuate fibers), the ventral two-thirds of the spinal fifth tract and its nucleus.

Cases 12 and 13.—Müller,[35] 1906, reported two cases which were perfectly typical, though there were no necropsies. In the first case, the left side of the face showed marked hypalgesia and hypothermesthesia. The disturbance was most marked in the region of distribution of the first branch of the fifth nerve, and did not include the mucous membrane of the mouth and tongue. All forms of sensations of the right side of the face were undisturbed, as was also tactile sensibility of the left side of the face.

In the second case there was a similar hypalgesia and hypothermesthesia which involved, however, the right side of the face. In this case, again, the most marked disturbances were in the region of distribution of the ophthalmic division of the fifth nerve. There was, in addition, a continuous subjective sensation of warmth on the right side of the face. Tactile sensibility was entirely intact on this side of the face and all sensibility was normal on the left side of the face.

Case 14.—A case with fatal termination and necropsy twelve days after the onset of the symptoms, was reported in 1907 by Thomas,[36] before the American Neurological Association. From the onset, there was subjective pain and dis-

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33. Rossolimo, G.: Thermoanästhesie und Analgesie als Symptomen von Herderkrankung des Hirnstammes, Deutsch. Ztschr. f. Nervenh. **23**:241, 1903.

34. Mai, E.: Ueber gekreuzte Lähmung des Kältsinnes, Arch. f. Psychiat. u. Nervenh. **38**:182, 1903.

35. Müller, E.: Ueber ein eigenartiges scheinbar typisches Symptomenbild bei apoplectiformer Bulbarlähmung, Deutsch. Ztschr. f. Nervenh. **31**:452, 1906.

36. Thomas, H. M.: Symptoms Following the Occlusion of the Posterior Inferior Cerebellar Artery, J. Nerv. & Ment. Dis. **34**:48, 1907.

turbance of pain and temperature sensibility on the right side of the face. This region was also completely dry, as the result of a complete adiaphoresis which accompanied the other symptoms.

The necropsy disclosed a thrombus in the right vertebral artery, which extended into the posterior inferior cerebellar artery. Thomas did not find any marked microscopic lesions in the medulla, so could not describe the structures which were involved.

Case 15.—In 1908, Mauss[37] reported a case which showed the symptoms typical of occlusion of the posterior inferior cerebellar artery. He had no necropsy to check his diagnosis. Painful sensibility of the whole left side of the face, particularly on the forehead and cheek, was markedly diminished. Hot and cold sensibilities were diminished in the whole of the left trigeminal area, whereas tactile sensibility in this region showed no variation from the normal.

Case 16.—Wilson,[38] 1909, reported, before the Royal Society of London, a case showing the same typical syndrome. The symptoms were: loss of pain sensibility over all of the left side of the face and the left eyeball; painful stimuli, such as the prick of a pin, were felt as simple pressure; loss of cutaneous pain sensibility of the left side of the mouth, tongue, palate, fauces, uvula, and pharynx; loss of sensibility to all degrees of heat and cold on the left side of the face, and anhidrosis and vasomotor disturbances in the same region. Tactile sensibility and localization of touch were intact on both sides of the face, as was the motor control of the muscles innervated through the motor root of the fifth nerve.

Case 17.—Harris,[39] 1910, also reported a case before the Royal Society of Medicine of London. The patient complained of a severe neuralgia of the left side of the face, which was particularly localized over the malar bone, above the left temple, and, at first, on the left side of the nose. Examination showed an analgesia and athermesthesia over the whole left side of the face, but no disturbance of tactile sensibility on either side. This case may be diagnosed as occlusion of the posterior inferior cerebellar artery notwithstanding the lack of a necropsy, as the typical syndrome which follows this lesion was observed.

Case 18.—In the same year, 1910, Ludin[40] described a case of thrombosis of the left vertebral artery, which had come to necropsy. Examination disclosed an analgesia and athermesthesia of the left side of the face and a slight disturbance of pain and temperature sensibility on the right side of the forehead. Tactile sensibility over the whole body was normal, as was motor control (the author does not mention the muscles of mastication in particular, so they were undoubtedly capable of function).

The necropsy disclosed, in the left vertebral artery, a thrombus which occluded the opening of its posterior inferior cerebellar branch. Histologic

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37. Mauss, T.: Klinische Beiträge zur Diagnostik Bulbäre Herderkrankungen, Deutsch. Ztschr. f. Nervenh. **34**:398, 1908.

38. Wilson, S. A. K.: A Case of Thrombosis of the Left Posterior Inferior Cerebellar Artery, Proc. Roy. Soc. Med., Neurol. Sect. **2**:52, Pt. 2, 1909.

39. Harris, W.: A Case of Thrombosis of the Left Posterior Inferior Cerebellar Artery Followed by Severe Trigeminal Neuralgia in the Analgesic Facial Area, Proc. Roy. Soc. Med., Neurol. Sec. **3**:81, Part 2, 1910.

40. Ludin, M.: Ueber Thrombose der Arteria vertebralis, Deutsch. Ztschr. f. Nervenheilk. **40**:380, 1910.

examination of the medulla revealed a lesion at the level of the middle third of the olive, which included: the formatio reticularis, the nucleus ambiguus, the spinocerebellar, spinotectal and spinothalamic tracts, a small part of the restiform body, the substantia gelatinosa Rolandi, and the spinal root of the fifth nerve.

The symptoms in this case were somewhat atypical, in that there was a disturbance in pain and temperature sensibilities on the side of the forehead opposite to the lesion. It may be noted that Ludin mentions only a "disturbance" of these sensibilities on the right, rather than a lack of them such as existed on the left side. It is possible that this disturbance was due to involvement of some secondary trigeminal fibers as they passed through the reticular formation from right to left, as the whole reticular formation was evidently involved in the lesion.

Cases 19, 20, and 21.—In 1911, Gordinier[24] reported three cases which, from the clinical picture, he diagnosed as occlusion of the posterior inferior cerebellar artery, though no necropsies were obtained. The first case was very incomplete, mention being made only of tactile sensibility, which was normal upon both sides of the face. The second case showed complete loss of pain and temperature sensibilities over the whole of the left side of the face; the tactile sensibility of that side was entirely normal. The third case showed, in addition to a distinct reduction in pain and temperature sensibilities over the whole of the right trigeminal area, a marked anhidrosis of the right side of the face. Tactile sensibility was intact over the whole of the body.

Case 22.—In the same year, 1911, Head and Holmes[41] described a case which they called occlusion of the posterior inferior cerebellar artery. They used a prick of calibrated intensity to test pain sensibility, cotton wool to test tactile sensibility, and metal tubes (silver, 1.25 cm. in diameter) filled with water at various temperatures to test thermal sensibility. Examination revealed an insensibiliy to prick over the whole left side of the face. The threshold stimuli for pressure-pain, tactile, and thermal sensations were normal and equal on the two halves of the face. The patient complained, however, that all temperature seemed "duller" on the left side of the face than on the right.

Case 23.—Courtney[42] reported a case in 1912 which, from its typical syndrome, he believed to be due to thrombosis of the left posterior inferior cerebellar artery. Tactile sensibility was well preserved on the right side of the face, while pain was markedly blunted. Heat was perceived in part, as such, and cold, when felt at all, produced a sensation of warmth.

Case 24.—Salmon,[43] 1912, reported a case of occlusion of the posterior inferior cerebellar artery with typical symptoms. He observed: complete insensibility to thermal, painful, and electric stimuli in the region of the face supplied by the second division of the right trigeminal nerve; slight diminution in these forms of sensibility in the remainder of the right side of the face; subjective neuralgia in the same region, accompanied by a subjective

41. Head, H., and Holmes, G.: Sensory Disturbances from Cerebral Lesions, Brain **34**:102, 1911.

42. Courtney, J. W.: A Case of Thrombosis of the Left Posterior Inferior Cerebellar Artery, Boston M. & S. J. **166**:329, 1912.

43. Salmon, D. A.: Di un Caso di Trombosi dell' arteria Vertebrale a della Cerebellare Posteriore ed Inferiore, Sperimentale **66**:442, 1912.

feeling of extreme cold or, as the patient described it, "petrifaction"; distinct anhidrosis on the right side of the face and hyperhidrosis on the left side. Tactile sensibility was absolutely normal on both sides of the face.

Case 25.—The next year, 1913, Robinson[44] reported a typical case. He used the usual pin prick test for pain sensibility, and for tactile sensibility he used in addition to cotton wool, Von Frey's hairs. On the left side of the face, he found an absence of sweating, and a subjective feeling of numbness. Tactile sensibility was normal over the whole body except on the left cornea, from which tactile stimuli elicited no response. Painful sensibility was decreased over the whole of the left side of the face; and heat and cold sensations, though produced by equally weak stimuli on both sides, were much duller from the left than from the right side of the face. The control of the muscles innervated by the fifth nerve was intact.

Case 26.—Cadwalader,[45] 1913, reported a case which he believed due to partial occlusion of the posterior inferior cerebellar artery by a thrombus. The patient showed a distinct diminution of heat, cold, and painful sensibilities within the region of distribution of the second division of the trigeminal nerve. The area involved was about the size of a fifty cent piece, and lay just over the malar bone. It did not extend forward to the nose, nor backward to the ear, nor was either cornea anesthetic. The nasal mucous membrane showed its normal sensibility, while that of the mouth and pharynx was almost insensitive. Tactile sensibility was unimpaired over both sides of the face.

Cases 27, 28, 29, 30, 31 and 32.—In 1913, Goldstein and Baum[46] reported six cases of occlusion of the posterior inferior cerebellar artery, but gave, however, very meager data. In their first case, they reported disturbed sensibility on the right side of the face and tongue, but failed to mention either the type of sensibility which was involved, the nature of the disturbance, or the method they used to test for sensibility. Accompanying the sensory disturbance, there was a right sided conjunctivitis. The necropsy in this case revealed a degeneration of the spinal root of the right trigeminal nerve and of part of the substantia gelatinosa.

In the second case the threshold for painful stimuli on the right side was much higher than on the left, which was normal. They reported the right spinal fifth tract partially destroyed, but failed to locate the lesion more accurately.

The third case was more complete. The left conjunctival and corneal reflexes were absent, and painful sensibility on the left side of the nose, cheek and tongue was lacking. Tactile sensibility on the whole of the face was entirely normal. The necropsy disclosed a lesion in the spinal fifth tract, the exact location of which the authors did not specify.

Their fourth case showed a lessened sensibility to pain on the right side of the face, accompanied by loss of the corneal and conjunctival reflexes on the same side.

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44. Robinson, G. W.: Occlusion of the Posterior Inferior Cerebellar Artery, J. A. M. A. **61**:179 (July 19) 1913.

45. Cadwalader, W. B.: Thrombosis of the Right Posterior Inferior Cerebellar Artery, J. Nerv. & Ment. Dis. **41**:375, 1913.

46. Goldstein, K., and Baum, H.: Klinische und anatomische Beiträge zur Lehre von Verstopfung der Arteria cerebelli posterior inferior, Arch. f. Psychiat. **52**:335, 1913.

In the fifth case, the sensibilities to temperature and pain of the left side of the face were entirely destroyed; corneal and conjunctival reflexes were partially lost on this side, and a subjective pain was felt in the same area.

The sixth case showed disturbance of pain and temperature sensibilities on the left side of the face and, on this same side, subjective painful and cold sensations.

In spite of their incompleteness, these cases point to a relationship between disturbance in pain and temperature sensibilities and destruction of the spinal fifth tract.

Cases 33 and 34.—Two cases, in which the symptoms were very typical, but in which no necropsies were performed, were reported in 1914, by Gillis.[47] In the first case, there was absolute loss of pain and temperature sensibilities of the part of the face innervated by the first and second branches of the right trigeminal nerve, and a subjective numbness of the same region. There was ptosis of the lid, complete anesthesia of the cornea and conjunctiva, and enophthalmus of the eyeball on the right side; and the patient complained of a "peculiar feeling" in the right eye, and that his right nostril felt swollen. Tactile sensibility and tactile discrimination, as tested with cotton wool and a compass respectively, were found to be normal over the entire body.

The second case showed a complete analgesia and a hypothermesthesia of the upper part of the right side of the face, and an entire absence of corneal and conjunctival reflexes. Heat, warmth, and cold, when perceived at all, were accompanied by unpleasant affective elements. Tactile sensibility, as in the last case, was entirely normal.

Case 35.—In the next year, 1915, an unusually good report of a case of occlusion of the posterior inferior cerebellar artery was published by Winkler.[48] He found painful sensibility destroyed and thermal sensibility much diminished (melting ice felt only cool, and hot objects, warm) throughout the whole of the left trigeminal area. The boundary line of this area was carefully determined. Anteriorly it corresponded with the median line, then passed over the top of the head, and returned in front of the ear and along the chin to again reach the median line. The left half of the oral cavity was analgesic, the tongue and palate being involved up to the midline; the left cornea was entirely anesthetic and no reflexes could be elicited from it nor from the conjunctiva. The palate and left side of the face were swollen; the latter was also markedly hyperemic and hot to the touch, but exhibited no trophic abnormalities. Winkler employed a plug of cotton wool, a small pencil and a pair of compasses to test tactile sensibility and localization, and found them diminished on both sides; but the motor control of all muscles innervated by the trigeminal nerve was entirely normal.

Case 36.—In the same year, 1915, Spiller[49] described a case of occlusion of this same artery. The left side of the face was entirely insensitive to pain (pin prick), except over a small area below the mouth. Temperature sensibility was quite normal, though subjective "burning" in the region of distribution of the supraorbital nerve was noted. Tactile sensibility was intact

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47. Gillis, A. C.: Occlusion of the Posterior Inferior Cerebellar Artery, J. A. M. A. **63**:1550 (Oct. 31) 1914.

48. Winkler, C.: A Case of Occlusion of the Arteria Cerebelli Posterior Inferior, Proc. k. Acad. v. Wetensch. Amsterdam, versl. **17**: Pt. 2, 914, 1915.

49. Spiller, W. G.: Remarks on the Central Representation of Sensation, J. Nerv. & Ment. Dis. **42**:399, 1915.

over the whole face. Spiller concluded from this case that there is a differentiation of pain from temperature fibers in the spinal tract of the fifth nerve.

Case 37.—In 1919, a case was reported by Hausman.[50] He found analgesia of the entire left side of the face, and complete athermesthesia of the left temple, left cheek, and left side of the forehead, whereas tactile sensibility, tested with cotton wool, was normal over the whole of the face.

Case 38.—Owen and Leighton,[51] 1919, published the discussion of a slightly atypical case. They found that the right side of the face was insensitive to temperature stimuli; the face on the right, the inner cheek on the left, and the forehead, tongue, palate, and pharynx on both sides, were insensitive to pain. Tactile sensibility, tactile discrimination, and tickle sense were normal on both sides.

The bilateral disturbance on the forehead, and in the mouth and pharynx is obviously an aberrant condition, and may well be due to involvement of the secondary fibers of the fifth as they cross in the reticular formation from left to right (see Case 18).

Case 39.—The last case published is that of Hall,[52] 1920. The report was most incomplete, but the symptoms mentioned were quite typical. He wrote of a hemianesthesia on the right side of the face, but obviously included only pain and temperature sensibilities in this term, for he also stated that tactile and proprioceptive sensations were normal everywhere.

CASES WITH OTHER LESIONS

Besides cases of occlusion of the posterior inferior cerebellar artery, there have been other cases recorded in the literature, syringomyelia or hemorrhage directly into the brain substance, which have given symptoms of particular interest in the study of the central connections of the fifth nerve.

Case 1.—The first case was reported by Wallenberg[11] in 1904. The patient showed marked disturbance in painful sensibility and a lesser disturbance in that of temperature on the right side of the face, which included the bridge of the nose, the lips, and the mucous membrane of the mouth and tongue. Touch was normal over the whole of the face.

At the necropsy he found a lesion in the medulla which involved the right spinal fifth nucleus, a few cells in the main sensory nucleus, and the dorsal part of the spinal root. In this case, though a few cells in the main sensory nucleus were destroyed, tactile sensibility was intact. Probably the injury was so slight that the overlap in distribution of fibers masked any deficiency. The lesion in the spinal root and nucleus account for the disturbance in pain and temperature sensibilities.

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50. Hausman, L.: A Case of Occlusion of the Posterior Inferior Cerebellar Artery with Cardiac Manifestations and Involvement of the Left Vagus Nucleus, Arch. Neurol. & Psychiat. **1**:145 (Feb.) 1919.

51. Owen, S. A., and Leighton, P. A.: A Case of Medullary Symptom-Complex Dependent on a Lesion of the Left Posterior Inferior Cerebellar Artery, Lancet **1**:1024 (June 14) 1919.

52. Hall, G. W.: Occlusion of the Right Posterior Inferior Cerebellar Artery, Arch. Neurol. & Psychiat. **3**:584, 1920.

Case 2.—In 1906, Head and Thompson[53] reported a case of progressive syringomyelia. Examination showed analgesia and hypothermesthesia of the entire face. Heat was recognized a little more easily than cold, especially on the left side. The patient complained of a subjective "peculiar" sensation on the left side of the face, which felt as if it had been rubbed with menthol. Tactile sensibility (cotton wool), discrimination, and localization over the whole body were perfectly normal, as was the motor control of the muscles innervated by the fifth. (Only a motor disturbance of the fingers and hand is mentioned.)

The main sensory nucleus and the motor nucleus of the fifth nerve are so very close together that it seems probable that a lesion in one, marked enough to show a disturbance, would also involve the other. As the motor nucleus was not injured, it may be concluded, even in the absence of necropsy, that the main sensory nucleus was also spared.

Cases 3, 4 and 5.—Three cases of syringomyelia were reported by Kutner and Kramer[22] in 1907. The first case (Case 7 in their paper) showed a disturbance in the painful sensibility of the right side of the cheek and nose. Neither temperature nor touch sensibilities were disturbed, and the motor functions of the fifth were also entirely normal.

The lesion found at the necropsy included most of the spinal fifth nucleus, which showed considerable shrinkage, though it was not entirely gone. The upper part of the spinal and all of the main sensory nucleus were spared.

The second case (their Case 13) showed a disturbance of temperature and pain sensibilities in a semicircular area on the right side of the face, which extended from the forehead, halfway between the scalp and the eyebrows, to the middle of the chin. As the disease progressed, the boundary of the disturbed area advanced peripherally as a widening semicircle. At no time was there any disturbance of the motor fifth nerve.

The last case (their Case 14) showed a total loss of sensibility to both pain and temperature on the left side. The authors do not mention either tactile sensibility or motor fifth activity.

Case 6.—Spiller,[54] in 1911, reported a case of syringomyelia which showed a complete loss of sensibility to pain, heat, and cold over the left side of the forehead, chin, and neck, and a partial loss over the left eyebrow and the cheek below the eye. The left side of the forehead also showed a slight diminution in tactile sensibility. There was, unfortunately, no necropsy in this case.

Case 7.—Brun,[55] 1912, published a very complete report of a case. Tactile sensibility, as tested with delicate hairs and cotton wool, was intact over the whole face, and motor activity of the trigeminal was also entirely normal. Temperature and pain sensibilities, however, were greatly disturbed. On the right side: sensations of pain (needle prick) were absent from the whole face; warm

53. Head, H., and Thompson, T.: The Grouping of Afferent Impulses Within the Spinal Cord, Brain **29**:536, 1906.

54. Spiller, W. G.: Disturbances of Sensation in the Face in a Case of Syringomyelia, Indicating That the Upper Branch of the Trifacial Nerve Descends Lowest in the Medulla Oblongata, J. Nerv. & Ment. Dis. **38**:553, 1911.

55. Brun, R.: Ein Fall von doppelseitigen symmetrischen Erweichungszystem in verlangerten Mark nebst einem Herde im Kleinhirn, Arb. a. d. Hirnanat. Inst. in Zürich von Monakow **6**:273, 1912.

stimuli and cold stimuli could not be felt as such, although cold gave a "burning" pain on the upper third of the face, and on the lower two-thirds warmth was felt as cold; and reflexes from stimulation of the cornea, face, and mucous membrane were diminished. On the left side: there were athermesthesia and analgesia of the entire face except of the forehead and temple, and complete loss of the above mentioned reflexes.

The necropsy revealed, in the medulla, a syringomyelic cavity which occupied the area of the inner half of the substantia gelatinosa. The larger cells seemed to be involved in the degeneration, but the marginal cells were preserved. The degenerated region extended rostrad into the pons, and just reached the lower boundary of the main sensory nucleus; caudad, on the left side, it extended down to the cervical region, and the left spinal fifth tract was entirely degenerated; on the right side the dorsal part of the tract was spared, the central two-thirds alone showing a high grade degeneration.

Case 8.—In 1915, an unusual case of multiple sclerosis was reported by Spiller.[49] The area of softening, indicated by complete paralysis of the muscles innervated by the motor fifth, was in the upper part of the pons, and involved the motor nucleus of this nerve. Tactile sensibility of the entire face was abolished, while pain sensibility was undisturbed and only a very slight disturbance in temperature sensibility was observed on the right side of the forehead. As the lesion included the motor nucleus, it is probable that the main sensory nucleus was also involved and, possibly, also the upper part of the spinal nucleus.

This case is especially interesting because it is the reverse of all the others. As, in them, tactile sensibility and motor function were spared together, so, in this case, they are alike involved, whereas pain and temperature sensibilities, usually destroyed, are here preserved. Correspondingly, the symptoms in this case were due to destruction of the motor and main sensory nuclei, with preservation of the spinal tract and nucleus, while the other cases all showed, primarily, lesions of the spinal structures alone.

SUMMARY AND DISCUSSION OF CLINICAL CASES

The evidence yielded by these cases, and the conclusions which seem justified by it, may be briefly summarized. Many cases, at necropsy, were found to have lesions of the spinal tract and nucleus of the fifth nerve on one or both sides. Such cases showed diminution or loss of pain and temperature sensibilities in areas on corresponding sides of the head, but never, unless the lesion actually included the main sensory nucleus, disturbance of tactile sensibility (Brun [55]).

Other cases, which did not come to necropsy, showed the same dissociation of the tactile from the pain and temperature sensibilities of the head, with disturbances in the latter two; they also showed the other symptoms typical of occlusion of the posterior inferior cerebellar artery. As the region supplied by this artery extends rostrad, only to the lower border of the pons, the main sensory nucleus of the fifth nerve must have been spared in all these cases, the spinal nucleus and tract alone being involved.

In all these cases with sensory disturbances of pain and temperature but not of touch, additional evidence that the main sensory nucleus remained intact was found in the continuation of the normal function

of the motor fifth. The main sensory and the motor nuclei are so close together that they can be entirely distinguished only by differences in their cells, and, as shown by at least one case (Spiller [49]), injury of the one would assuredly have been accompanied by injury of the other. As the motor nucleus must have remained intact in these cases, we may conclude that the main sensory nucleus was likewise uninjured.

One case is recorded which showed loss of tactile sensibility but not of pain and temperature sensibilities. Since in this case the masticatory muscles were paralysed, and no disturbance of medullary centers was indicated, it may be concluded that the main sensory nucleus, but not the spinal structures of the fifth nerve, was destroyed.

Thermal sensibility is disturbed in various ways. In many cases it is entirely abolished; in others only sensibility to heat is impaired, cold being felt in a normal manner; and in still others the application of heat elicited a sensation of cold, or cold a sensation of heat. The loss of heat sensibility but not of cold, in some cases, suggests a segregation of these fibers within the spinal fifth tract in the medulla.

Besides the objective symptoms, many patients reported subjective pain and temperature sensations in the anesthetic region. This may be attributed to a zone of hyperirritability surrounding the area of destruction. The frequent disturbance of sweat secretion in the areas of athermesthesia is of interest.

The most important conclusion which may be drawn from the above data is that the afferent impulses of pain and thermal sensibilities from the fifth nerve descend through the medulla in the spinal tract of that nerve, and pass at various levels to the cells of the spinal nucleus; whereas, the tactile impulses from the face pass to the cells of the main sensory nucleus. Such a distribution has been previously suggested by Winkler,[48] and Spiller.[49]

III. EXPERIMENTAL WORK

The experiments to be described were carried out to test the validity, under more accurately controlled conditions, of the conclusion arrived at by a survey of the clinical evidence—that tactile impulses reached the main sensory nucleus of the fifth nerve, whereas thermal and painful impulses reached the spinal nucleus. We were able to cut the spinal root of the fifth nerve in the medulla at a level just below the bifurcation of the sensory fibers. This cut severed the whole of the spinal fifth tract from its peripheral portion, but left intact the fibers destined for the main sensory nucleus. The appearance or non-appearance of reflex activity in response to various stimuli, was the test used to determine which types of sensibility were impaired by the interruption of the spinal tract, and which types were left intact.

This method necessitated an exact knowledge of the sensory innervation of the face, especially of any overlapping of the two trigeminal areas at the median region, as a double sensory path would insure the presence of reflex activity even if one path were interrupted as described. To this end the whole fifth nerve on one side was completely severed proximal to the ganglion and the reflex activity from stimuli on both sides of the face was carefully tested.

A second objective of this research was the determination of the lowest level at which interruption of the spinal fifth root would still cause a dissociation of pain and tactile sensibility. For this purpose, we severed the root at various levels between the region of the origin of the tract and the region of the bifurcation of the pyramids, and again tested the integrity of the sensory paths by the presence or absence of a reflex involving them. Since cats are easier to work with than dogs, and also yield more delicate vasomotor reflexes, these animals were used throughout the course of the experiments.

SURGICAL TECHNIC

In the majority of the cases, urethane was used as the anesthetic, because reflex activity is not depressed, but rather facilitated, by this drug, and it was, therefore, particularly favorable for this work. An intraperitoneal injection of 0.75 gram of urethane (in solution) per kilogram of body weight was found to be satisfactory. In a few cases, when surgical anesthesia could not be produced by urethane alone, ether was used with it, and was given either by mask or by tracheal cannula. When reflexes were not to be tested till several days after the operation, the cats were anesthetised with ether alone, given by mask.

Entrance into the cranium and exposure of the spinal root of the fifth nerve was effected in two ways: (1) through the roof of the mouth, and (2) through the occipital bone. For the first approach, the cat was tied, dorsal side down, with the head just over the end of a board, the mouth was clamped open by a device arranged to keep it at its maximum opening, and the tongue was pulled out and tied. A cut was then made through the middle of the soft palate, and the two flaps, so formed, were held apart by threads which passed through each and were tied together over the bridge of the nose. This exposed the posterior wall of the nasopharynx. The mucous membrane was scraped with a chisel from the tympanic bulla and from the whole area of the basilar part of the occipital bone, laterad to the midline; then, with a dentist's drill, about three millimeters in diameter, the scraped medial wall of the tympanic bulla was removed. After removal of the bulla, which overhangs the occipital bone, it was possible to bore a hole in the latter just mediad to the bulla at its posterior third. The hole was made four to five millimeters in diameter and was

extended into the cranial cavity, where it usually opened into the inferior petrosal sinus. The resulting hemorrhage was allowed to drain into the mouth so that no intracranial clots, which would press upon the medulla, would be formed; the bleeding usually stopped in two or three minutes, when a small part of the medulla could be seen through the hole. This was the ventrolateral portion of the medulla at the level of the dorsal cochlear nucleus.

The spinal trigeminal fibers were cut with a curved cataract knife which had been ground so that only the distal centimeter possessed a cutting edge. This knife, held vertically with its cutting edge turned laterad, was passed through the hole in the bone and through the underlying medulla until its point reached the covering bone. The knife thus passed entirely through the medulla, from ventral to dorsal surfaces, just mediad to the fifth tract, and had its cutting edge directed towards that tract. The blade was then forced laterad by moving the handle in a medial direction, the hole in the bone serving as fulcrum; it was forced ventrad by raising the whole knife. The cut so made included the whole of the spinal fifth tract, a small area of the nucleus of the tract, and, occasionally, a small part of the restiform body and the overlying dorsal cochlear nucleus. The exact lesion produced was always checked by necropsy.

Occasionally the cat showed signs of shock after cutting the medulla. When apnea supervened, artificial respiration in the form of an interrupted air current was used.[56] The sensory tests were never made until the cat showed complete recovery from shock, so that the reflexes were as lively as in the normal animal.

When desired, blood pressure was taken from the carotid artery with a mercury manometer, and respiration was recorded from a tracheal cannula with attached tambour.

This method of severing the spinal tract proved to be most satisfactory when animals were to be experimented upon immediately. There was but little hemorrhage and only slight trauma to the tissues, and, therefore, less shock from the operation. It did not permit one, however, to make the cut accurately at a desired level, because the area exposed was small and the position of the medulla in the cranium slightly inconstant. For those experiments, therefore, in which it was essential to know the exact level of the cut, and desirable to make

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56. It is interesting to note that very often diaphragmatic breathing alone reappeared, the thoracic muscles never regaining activity. It is possible that the afferent path for the respiratory reflex to the intercostals was interrupted. Coombs and Pike (The Rôle of Afferent Impulses in the Control of Respiratory Movements, Proc. Soc. Exper. Biol. & Med. **15**:55, 1918) believe that the impulse must ascend as far as the corpora quadrigemina before a reflex can result.

several cuts at different levels, the entrance into the cranium was made through the occipital bone in the following manner.

The hair was clipped from the dorsal surface of the head and neck, and the skin was cut from the vertex capitis down to the level of the first or second cervical vertebra. On the side on which the medulla was to be exposed, a cross cut was made mid-way between the ends of the longitudinal cut and was extended laterad to the ear. The two resulting flaps of skin were reflected and held out of the field by towel forceps. To eliminate hemorrhage as much as possible, a small amount of a 1:1000 solution of epinephrin hydrochloride was injected into the muscles along the line in which they were to be divided.

The muscles attached on either side of one lateral half of the inferior nuchal ridge were cut as near to the bone as possible; and also, by a second cut at right angles to the first, which extended rostrad as far as the superior nuchal line and caudad to the inferior edge of the first cervical vertebra, the muscles along the external occipital crest were divided. The bits of muscle which remained were scraped away from the underlying bone with a small periosteal elevator.

On the one side, then, the surface of the occipital bone was entirely clean. In this area, a circle of bone, with the superior nuchal line as a diameter, was ground very thin, by the use of the dentist's drill already mentioned, and the remaining sheet was removed with bone forceps. The preliminary grinding considerably reduced the amount of hemorrhage from the bone, and bone wax pressed into the open edges stopped the little which was unavoidable. After the circle of bone had been entirely removed, the dura mater covering the posterior part of the cerebellum and the lower and lateral part of the medulla could be seen. This dura was opened over the cerebellum to preclude any possibility of injuring the medulla. The cerebrospinal fluid was allowed to drain and the cerebellum was then lifted up and held backward, with a small retractor, in such a way that the whole lateral wall of the medulla could be seen. The spinal fifth tract was thus exposed along the whole of its course through the medulla and, with the knife already described, could be cut at any desired level without injury to adjacent structures.

This operation, in contrast to the other, involved much trauma and hemorrhage, and left the animal in a shocked condition. The muscles were, therefore, sewed back into place, the skin was sutured over the wound, and the cat was allowed to recover from the operation. Usually 20 to 50 c.c. of sterile isotonic saline solution was injected intravenously. From five to twenty-four hours after the operation the cat, as a rule, showed sufficient recovery to permit the continuation of the experiments.

Another method was used to cut the whole fifth nerve before it enters the pons (trigeminal neurectomy). This was always performed under strict asepsis and the cats were allowed to live for several days. The hair was thoroughly removed from the head anterior to the ear, and a skin incision was made just in front of the ear perpendicular to the main axis of the body. The temporal muscle thus exposed, was then cut and scraped from the underlying bone. A hole, 1.5 centimeters in diameter, was trephined through the frontal bone over the lateral edge of the frontal lobe of the hemisphere. This lobe was lifted with a small retractor, from the floor of the cranium, and the Gasserian ganglion in its depression on the apex of the petrous portion of the temporal bone was exposed. A cut was then made through the whole nerve proximal to the ganglion with a curved knife similar to that already described. The muscles and skin were sutured in the usual way and the cat was allowed several days in which to recover from the operation. It was found necessary after the operation to clean the eyes daily with mild protargin.

METHODS OF EXPERIMENTATION

At first, we attempted to test pain sensibility in different parts of the face by stimulation with needle electrodes which pierced the skin. This method was found to be very unsatisfactory; the cat repeatedly reacted to painful stimuli even after the spinal tract had been completely severed. The possibility suggested itself that deep pain fibers were present in branches of the seventh nerve which supply the muscles of expression, and that these afforded an afferent path for pain reflexes. In confirmation of this, we found that electrical stimulation on both sides of the face elicited reflexes in the cats with the entire fifth nerve cut on one side. It is interesting to note in this connection that Maloney and Kennedy,[57] 1911, demonstrated in man that deep sensibility of the face is retained after gasserectomy.

Since it was impossible satisfactorily to eliminate sensations carried by the seventh nerve, from this field, we chose to stimulate the cornea only. This is a particularly favorable region in which to test painful sensibility, as it is innervated exclusively by pain fibers from the fifth nerve (Schäfer[1]). The nictitating membrane has a second sensory supply (either through overlapping of the opposite fifth, or from the seventh nerve), for stimulation of it called forth a response even with the entire fifth nerve on the same side cut. We were always careful, therefore, that the electrodes did not touch this membrane when we stimulated the cornea.

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57. Maloney, W. J., and Kennedy, R. F.: The Sense of Pressure in the Face, Eye and Tongue, Brain **34**:1, 1911.

When painful sensibility of the cornea was intact, stimulation with a tetanizing current caused typical reflexes. The lids closed tightly over the eyeball; there was bodily struggling; the forepaws moved toward the eye; and the blood pressure usually rose markedly, and was accompanied by an irregularity in the rate of respiration.

The most delicate test for tactile sensibility mediated through the trigeminal nerve, is the sneeze reflex; very light stimuli in the interior of the nostril are sufficient to bring forth marked sneezing. A fine camels hair brush of nine to ten hairs, or a little cotton wool on the end of a probe, touched lightly to the distal part of the nostril until the sneezing commenced, was found effective. The cat under urethane, but not ether, was found to be just as sensitive to such stimuli as an unanesthetized cat. The sneeze was registered in the respiratory tracing.

As a third test for the integrity of sensation in the trigeminal area, we used the oculocardiac reflex. A very excellent discussion and review of the literature on this reflex was given by Naccarati[58] in 1921. The reflex, described first by Dagnini and by Aschner in 1908, consists of a slowing of the pulse, a modification of respiratory rhythm and, rarely, a lowering of blood pressure, as the consequence of pressure on the eyeball of the subject. It is exaggerated by severing the cervical cord (which interrupts the sympathetic connections with the medulla), and is abolished by cutting both vagi, so that the efferent path of this reflex must lie in the vagi. The afferent path is in the fifth nerve, for injury to that nerve prevents the reflex. The response, Naccarati believes, is probably not due to stimulation of pain fibers, for it is not produced by painful pressure upon the mandible or forehead.

Urethane augments reflex vagal activity (Becht[59]), so that cats anesthetized by this drug are very favorable for this test. The reflex was elicited both by the usual pressure and by stimulation of the cornea with a tetanizing current, and the resultant slowing of the heart was recorded on the tracing from the carotid.

At the end of all experiments the cats were killed and necropsies were performed. The exact position of the cut was noted and the medulla was removed for histologic examination by the pyridin silver method of Ranson.[60] The tissue was imbedded in paraffin and cut in serial sections ten microns in thickness, in such a way that the fifth

58. Naccarati, S.: The Oculocardiac Reflex (Dagnini-Aschner Phenomenon), Its Use in Medicine and Psychology, Arch. Neurol. & Psychiat. **5**:40 (Jan.) 1921.

59. Becht, F. C.: Personal communication to the author, 1921.

60. Ranson, S. W.: The Pyridine Silver Method, with a Note on the Afferent Spinal Nonmedullated Nerve Fibers, Rev. Neurol. & Psychiat. **12**:467, 1914.

nerve could be followed into the medulla, the point of bifurcation of the fibers seen, and the whole spinal tract of the nerve below the level of the cut followed (Fig. 1). The whole of the lesion was always included in the material sectioned.

EXPERIMENTAL RESULTS

The sensitivity of the cornea to painful stimuli, that is, to a tetanizing current, was eliminated in each of the twenty-one cats in which the spinal root had been completely cut across. This analgesia appeared only on the side of the lesion, and did not involve the cornea

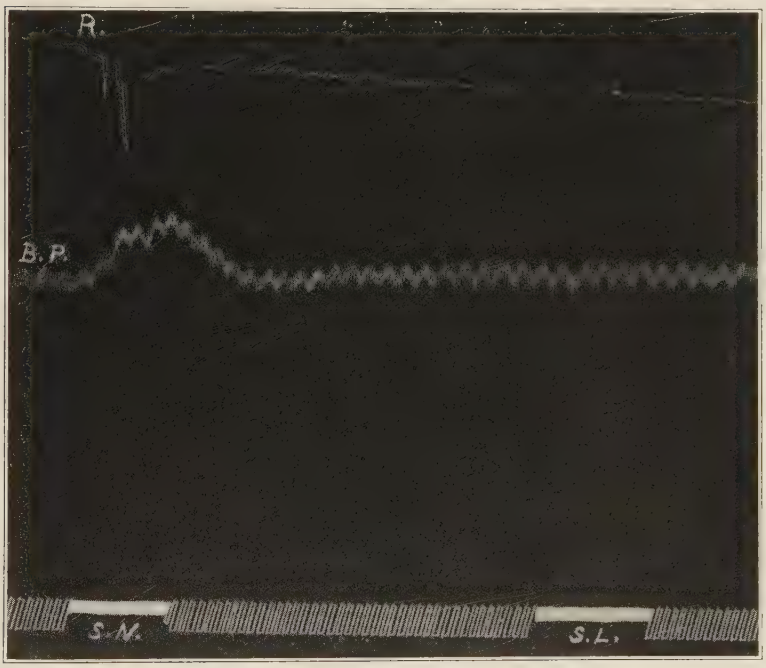

Fig. 2.—The vasomotor reflex from painful stimuli. *S N*, stimulation of the cornea on the normal side. *S L*, stimulation of the cornea on the side of the lesion. *R*, respiratory tracing. *B P*, blood pressure tracing.

of the normal side; stimulation of the latter always led to marked struggling, dilatation of both pupils, and a rise of 8 to 17 mm. in blood pressure. These are well recognized pain reflexes (Fig. 2).

The respiratory reflexes showed great variation. Stimulation of the analgesic cornea in no way modified respiration. Stimulation of the normal cornea caused: (1) no effect in four cats; (2) slight decrease in amplitude in three cats; (3) marked irregularity in seven cats; (4) apnea during stimulation in one cat; and (5) partial inhibition, followed by a period of marked irregularity, in one cat.

These respiratory variations were neither constant nor uniform enough to be considered as real indications of pain. The other reflex effects, struggling, dilatation of the pupils, and rise in blood pressure, were constant in their appearance, and may surely be interpreted as pain reactions. Since they were always present on the normal side and never on the side on which the spinal fifth tract had been cut, it seems reasonable to conclude that painful sensibility of the cornea was abolished by such a cut.

The sneeze reflex was used as a test for tactile sensibility on the last eleven cats. The touch of a little cotton wool in either nostril caused marked sneezing, preceded by licking movements of the tongue over the upper lip toward the nose. The reflex followed a latent period which varied from two or three seconds to seventy or seventy-five seconds and which was not constant even in one individual (Fig. 3). A rise in blood pressure usually accompanied the sneeze, but did not occur if the thorax was first opened; this indicated that the rise in blood pressure was secondary to the exaggerated inspiratory phase of respiration which precedes the sneeze. Cats with the spinal fifth tract of one side cut, and which were insensitive to painful stimuli of the cornea of that side, still gave a good sneeze reflex from tactile stimuli in either nostril. This was not due to an overlapping of fibers from the normal side, since four cats, with the whole sensory root of the trigeminal of one side cut, sneezed normally when stimulated with the camel hair brush on the normal side but did not sneeze or show any other indications of tactile sensibility when stimulated on the side on which the nerve had been cut. It may be noted that, in these cats, stimulation of either nostril with electrodes called forth marked pain reflexes. Either the pain fibers of the fifth nerve, in contrast to the tactile fibers, do overlap, or deep fibers from the seventh nerve were stimulated, or, possibly, the reaction was due merely to a spread of current, since the two nostrils are very close to each other.

Nor could the persistence of reflex effects from the nostril, after disappearance of those from the cornea, have resulted because the corneal fibers alone were included in the cut and on the assumption that the fibers which innervate the nostril terminate at a higher level of the spinal fifth tract than do those which innervate the cornea. In every case, except two, the tract was cut just below the bifurcation of the fibers, so that all the descending fibers must have been severed before any of them could have terminated. Only the fibers going to the main sensory nucleus were left, and the tactile sensations from the nose must, therefore, have passed along them.

Pressure on the eyeball of the normal side, in three cats under the influence of urethane only, caused distinct vagal slowing of the heart and also body struggling, while pressure on the eye of the side on

which the spinal fifth tract had been cut, in no case caused a response (Fig. 4). Electrical stimulation (tetanizing current) of the eyeball of the normal side, but not of the side which had been operated on, also led to slowing of the heart and to struggling movements. Since the tetanizing current, which certainly leads to painful sensations, produces the same effects as pressure, and since the responses to pressure stimuli

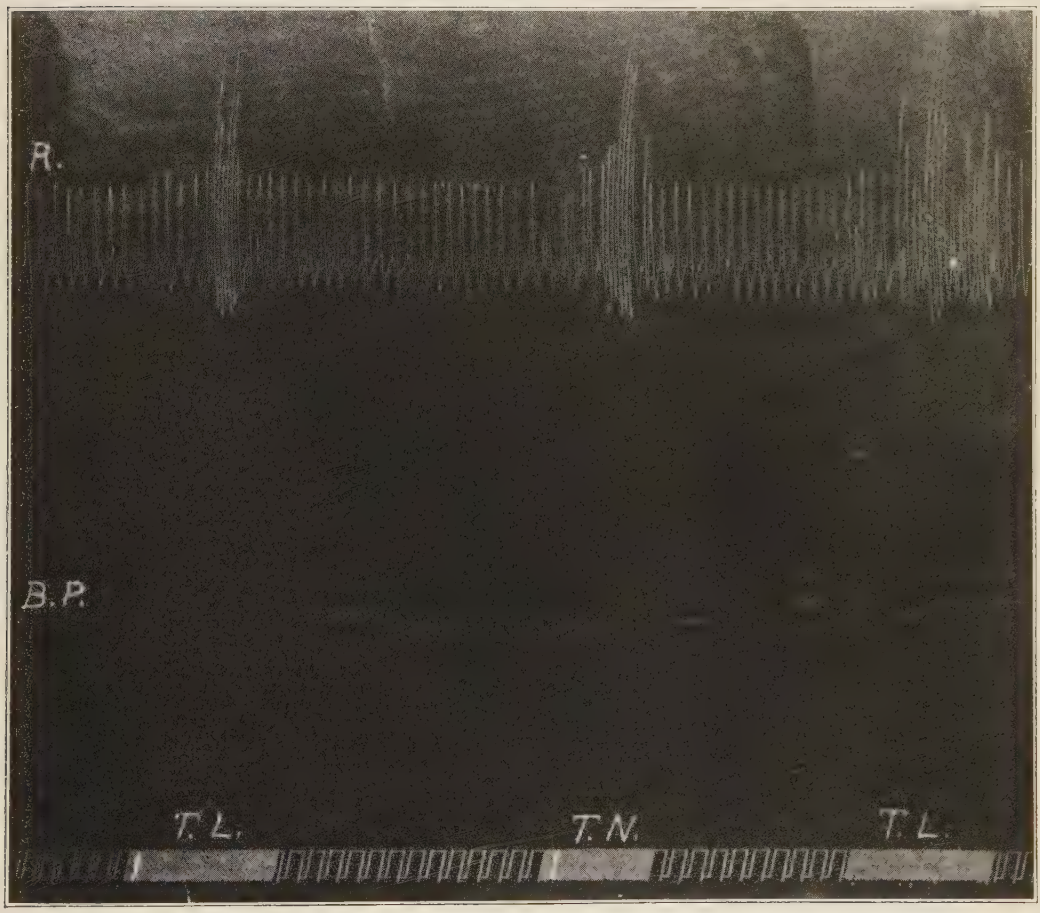

Fig. 3.—The sneezing reflex. *T L,* tickle of the nostril on the side of the lesion. *T N,* tickle of the nostril on the normal side. *R,* respiratory tracing. *B P,* blood pressure tracing.

are abolished by section of the spinal fifth tract, as are pain reactions, it seems that the oculocardiac reflex is due to stimulation of the pain fibers of the trigeminal nerve. Naccarati's observation that painful stimulation of the forehead and jaw does not slow the heart merely serves to emphasize the specific character of this reflex from the eye.

Histologic examination of the medullas showed that, in all cases in which the pain reflexes from the cornea had been entirely eliminated, the spinal fifth tract had been completely severed. In most, the spinal trigeminal nucleus and, occasionally, the reticular formation medial to the nucleus, were also slightly injured. The cut was usually found just below the bifurcation of the sensory fibers, but in two cases was about five millimeters below that point. The physiologic results in these two experiments were no different from the others. The cut was never found above the bifurcation of the sensory fibers, and the fibers going to the main sensory nucleus were intact in every case (Fig. 1).

In the preceding experiments, a high section of the spinal fifth tract was made. and histologic examination showed that the trigeminal fibers

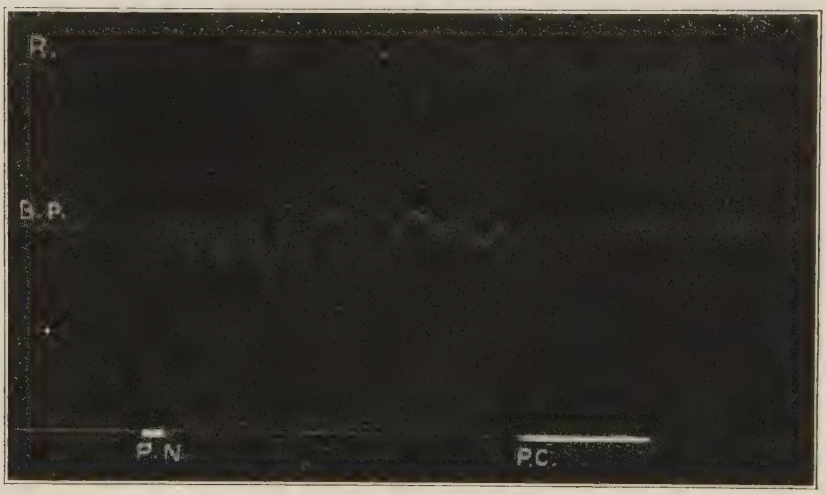

Fig. 4.—The oculocardiac reflex. *P N*, pressure on the eyeball of the normal side. *P C*, pressure on the eyeball of the side of the lesion. *R*, respiratory tracing. *B P*, blood pressure tracing.

had been cut just below their bifurcation, so that none of the descending fibers were left intact. To determine the level to which the pain fibers from the cornea descend before they terminate, a series of cuts in the tract were made, starting at the level of the obex, and gradually ascending the tract, until stimulation of the cornea no longer elicited reflexes. In four such cases, it was found that the cuts which eliminated the pain responses were 5.9, 6.7, 6.8 and 7.1 millimeters below the bifurcation of the fibers. In all except one case, the cut which proved effective was not more than 1.5 millimeters above the previous one (in the one exception, the effective cut was 2.1 millimeters above the previous one), so the margin of error was small.

These results indicate that the pain fibers from the cornea terminate just below the upper 5 to 7 mm. of the tract, and are in agreement with the clinical findings of Solder [19] and Schlesinger,[20] to which reference has already been made—that the fibers supplying the eye and nose terminate in the upper part of the tract.

COMMENT

The experimental results are thus in entire accord with the clinical evidence, and demonstrate that painful sensations from the trigeminal area pass only by way of the spinal fifth tract and nucleus, while tactile sensations from the same region travel by way of the main sensory nucleus. Besides its diagnostic value, this fact possesses significance in two connections.

The spinal fifth tract is the direct upward continuation of the tract of Lissauer, and the spinal fifth nucleus is continuous with the substantia galatinosa. Ranson [61] has demonstrated that pain fibers from the spinal nerves pass into the tract of Lissauer and terminate in the substantia gelatinosa; so that the essential similarity of the painful innervation of spinal and cranial regions becomes apparent. The spinal fifth and Lissauer's tracts, and the spinal fifth nucleus and substantia gelatinosa are thus not only anatomically continuous but also physiologically identical.

Most, if not all, of the sensory fibers of the trigeminal nerve bifurcate and the smaller branch of each passes exclusively to the main sensory nucleus, while the larger reaches only the spinal nucleus. The dissociation of pain and temperature might possibly be explained as follows. It has not been conclusively demonstrated that all fibers bifurcate. Possibly the small myelinated and unmyelinated fibers carry pain and enter the spinal tract without bifurcation; the larger fibers carry touch (and possibly temperature—this case is not so clear) and send branches to both nuclei. Tactile sensation, having a double path, would thus persist after separation of the spinal tract from the nerve, while painful sensation could not.

This explanation is improbable for two reasons. First the vast majority of the trigeminal fibers certainly bifurcate; it is not probable that only the small fraction which may not do so is concerned in the transmission of pain sensations, while the two, hardly more important, sensations of touch and temperature are so generously supplied with transits. Secondly, if tactile impulses may follow either one of two paths, injury to the main sensory nucleus should not block them any more than does injury of the spinal nucleus, and if both of the nuclei

61. Ranson, S. W.: An Experimental Study of Lissauer's Tract and the Dorsal Roots, J. Comp. Neurol. **24**:531, 1914.

were involved, pain, as well as touch sensibility, should be lost. Yet in one case of syringomyelia (Spiller,[49]) which involved the main sensory but not the spinal nucleus, pain was normal and touch was abolished. It appears, therefore, that pain impulses pass exclusively through descending fibers and touch impulses exclusively through ascending fibers. Since the ascending and descending fibers are, in most cases at least, branches of a single afferent fiber, it follows that both pain and touch impulses probably pass for a distance along the same nerve fiber.[62]

As Lucas[63] points out, the character of a nerve impulse depends only on the condition of the nerve through which it is passing and not at all on its past history. If one impulse which reaches the point of bifurcation of a fiber follows only one branch, so must all others; and, as in the case of the trigeminal fibers, if some impulses reach each nucleus, it follows that all impulses must reach both. Yet impulses originating in pain end-organs can produce conscious and reflex effects only when they reach the spinal nucleus, and impulses originating in tactile end-organs are effective only when they reach the main sensory nucleus, though all impulses reach both. The following explanation seems plausible.

Forbes and Gregg[64] have secured evidence that a single stimulus of an end-organ may cause a series of nerve impulses in rapid succession to pass along the nerve fiber. The frequency of impulses may be different for each type of end-organ, and two different synapses may be "attuned"[65] to different frequencies; so that the impulse frequency from a painful stimulus may be able to pass the synapse to the spinal nucleus but not the one to the main sensory nucleus, while the impulse frequency from a tactile stimulus may be able to pass only the latter. Such a relationship would account for the observed facts, and is being further investigated.

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62. Herrick, C. J.: An Introduction to Neurology, Philadelphia, W. B. Saunders Company, 1918.

63. Lucas, Keith: The Conduction of the Nervous Impulse, New York, Longmans, Green & Co., 1917.

64. Forbes, A., and Gregg, A.: Electrical Studies in Mammalian Reflexes, Am. J. Physiol. **39**:172, 1915.

65. Lucas (1917) suggests an "attunement" of this type. Immediately (0.002 sec.) after the passage of one impulse, a nerve fiber is entirely refractory to a second; later (0.013 sec.), a second impulse will be transmitted as one of low intensity; still later (0.03 sec.), as one of higher intensity than normal; and finally in the same manner as the first impulse was transmitted. The synapse is a region of conduction with a decrement, so that a series of impulses rapid enough to fall each in the relative refractory period of the last would be extinguished. One synapse might thus permit one frequency of sensory impulse to pass and bar a second, while another synapse, because of a different decrement, might act differently.

CONCLUSIONS

Besides offering data on the anatomy of the central trigeminal structures in cat and man, the following physiologic observations have been discussed:

1. Painful, and possibly thermal, stimuli in the trigeminal area produce conscious and reflex effects viâ the spinal fifth tract and nucleus only, while tactile stimuli produce effects viâ the main sensory fifth nucleus only (39 cases of occlusion of the posterior inferior cerebellar artery, 8 other human cases, and 21 cats with experimental lesions).

2. Pain fibers from the cornea terminate just below the upper seven millimeters of the spinal tract (cat). Pain fibers from adjacent regions descend further (human).

3. The fields of tactile sensibility of the two trigeminal nerves supplying the nose do not overlap (cat).

4. The adequate stimulus for the oculocardiac reflex is pain rather than pressure, and the reflex path includes the spinal fifth tract.

5. The spinal fifth tract and nucleus are functionally related to the tract of Lissauer and the substantia gelatinosa respectively.

6. Deep pain sensation from the facial muscles is probably carried by the facial nerve.

7. These results favor the view that impulses from more than one type of sensory stimulus may be transmitted by the same nerve fiber.

I am very grateful to Dr. L. E. Davis, who performed the trigeminal neurectomies; to Drs. S. W. Ranson and F. C. Brecht for aid and advice throughout the course of this research; and to Dr. R. W. Gerard for valuable suggestions, and for willing help in correcting the manuscript.

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